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## Drum Beating and a Martial Art Bojutsu Performed by a Humanoid Robot

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### 1. Introduction

Over the past few decades a considerable number of studies have been made on impact dynamics. Zheng and Hemami discussed a mathematical model of a robot that collides with an environment (Zheng & Hemami, 1985). When a robot arm fixed on the ground collides with a hard environment, the transition from the free space to constrained space may bring instability in the control system. Therefore, the impact between robots and environments has been the subject of controversy. Asada and Ogawa analyzed the dynamics of a robot arm interacting with an environment using the inverse inertia matrices (Asada & Ogawa, 1987). In the early 90's, the optimum approach velocity for force-controlled contact has been enthusiastically studied (Nagata et al., 1990, Kitagaki & Uchiyama, 1992). Volpe and Khosla proposed an impact control scheme for stable hard-on-hard contact of a robot arm with an environment (Volpe & Khosla, 1993). Mills and Lokhorst proposed a discontinuous control approach for the tasks that require robot arms to make a transition from non-contact motion to contact motion, and from contact motion to non-contact motion (Mills & Lokhorst, 1993). Walker proposed measures named the dynamic impact measure and the generalized impact measure to evaluate the effects of impact on robot arms (Walker, 1994). Mandal and Payandeh discussed a unified control strategy capable of achieving a stable contact against both hard and soft environment (Mandal & Payandeh, 1995). Tarn et al. proposed a sensor-referenced control method using positive acceleration feedback and switching control strategy for robot impact control (Tarn et al., 1996). Space robots does not have fixed bases, therefore, an impact with other free-floating objects may bring the space robots a catastrophe. In order to minimize the impulsive reaction force or attitude disturbance at the base of a space robot, strategies for colliding using reaction null-space have been proposed (Yoshida & Nenchev, 1995, Nenchev & Yoshida, 1998).

Most of the researches have been made to overcome the problems introduced by impacts between robots and environments. Some researchers have tried to use the advantages of impacts. When a robot applies a force statically on an environment, the magnitude of force is limited by the maximum torque of the actuators. In order to exert a large force on the environment beyond the limitation, applying impulsive force has been studied by a few researchers. Uchiyama performed a nail task by a 3-DOF robotic manipulator (Uchiyama, 1975). Takase et al. developed a two-arm robotic manipulator named Robot Carpenter, and performed sawing a wooden plate and nailing (Takase, 1990). Izumi and Hitaka proposed to use a flexible link manipulator for nailing task, because the flexible link has an advantage in absorbing an impact (Izumi & Kitaka, 1993).

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However, those works mentioned above were done using robotic manipulators fixed on the ground except for space robots, and thus, there was no need to take care about losing a balance. Humanoid robots are expected to work on human's behalf. If a humanoid robot can do heavy works utilizing an impulsive force as well as a human does, the humanoid robot will be widely used in various application fields such as constructions, civil works, and rescue activities.

The first attempt on an impact motion by a humanoid robot was reported in (Hwang et al., 2003). Matsumoto et al. performed a Karate-chop using a small humanoid robot and broke wooden plates (Matsumoto et al., 2004). In order for a legged robot to effectively exert a large force to an environment without losing a balance, working posture is important. Tagawa et al. proposed a firm standing of a quadruped for mobile manipulation (Tagawa et al., 2003). Konno et al. discussed an appropriate working posture of a humanoid robot (Konno et al., 2005).

This chapter addresses an impact motion performed by a humanoid robot HRP-2. A drum beating is taken as a case study, because it is a typical task that requires large impulsive forces. The drum beating motion is carefully designed to synchronize with music. The drum beating and a Japanese martial art Bojutsu were performed by a humanoid robot HRP-2 in the Prototype Robot Exhibition at Aichi Exposition 2005.

## 2. Why and Where Is an Impulsive Force Needed?

In order to show the advantages of using an impulsive force, a task of pushing a wall is taken as an example in this section. A model of a humanoid robot HRP-1 (the HONDA humanoid robot P3) is used in a simulation.

Fig. 1 shows the snapshots in a simulation in which the humanoid robot HRP-1 quasi-statically pushes a wall, while Fig. 2 shows the snapshots in a simulation in which the HRP-1 dynamically pushes a wall moving a body forward. In the simulation illustrated in Fig. 1, the body is fixed so that the projection of the centre of gravity (COG) comes on the middle of the fore foot and rear foot, while in the simulation illustrated in Fig. 2, the body is moved so that the projection of COG moves from the centre of rear foot to the centre of fore foot.

The results of the simulations are plotted in Fig. 3. Fig. 3 (a) shows the forces generated at the wrist (equal and opposite forces are generated on the wall) when the humanoid robot exerts a quasi-static force on a wall, while (b) shows the forces at the wrist when the humanoid robot dynamically exerts a force.

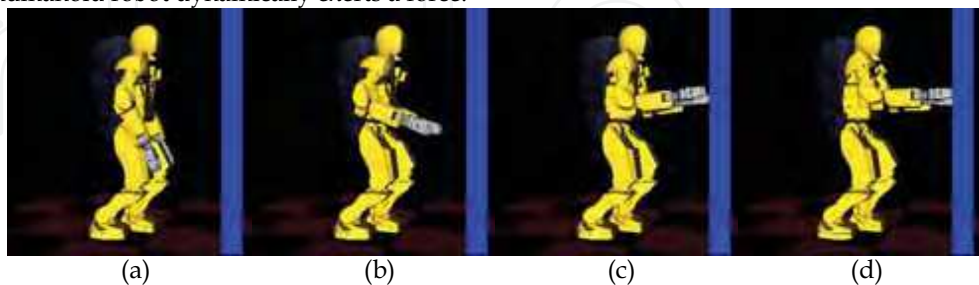


Fig. 1. A humanoid robot quasi-statically pushes a wall. The body is fixed so that the projection of the center of gravity (COG) comes on the middle of the fore foot and rear foot. (a) at 0.0 [s], (b) at 2.0 [s], (c) at 4.0 [s], and (d) at 6.0 [s].

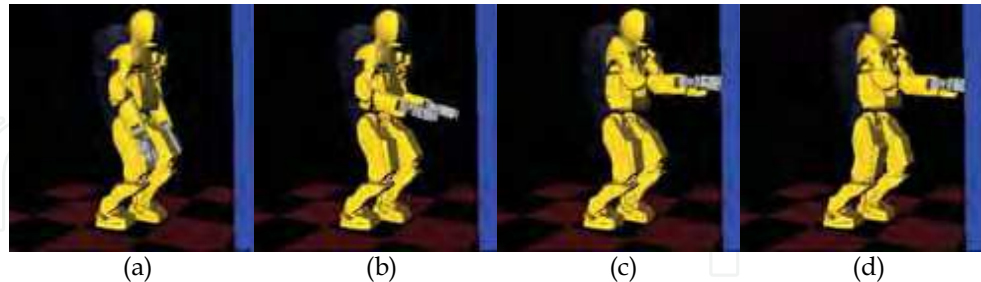


Fig. 2. A humanoid robot pushes a wall moving the body to apply an impulsive force. In order to accumulate momentum, the body is moved so that the projection of COG moves from the center of rear foot to the center of fore foot. (a) at 0.0 [s], (b) at 2.0 [s], (c) at 4.0 [s], and (d) at 6.0 [s].

As seen in Fig. 3, when the humanoid robot dynamically exerts a force on a wall, approximately 1.5 times larger force is generated compared with the case when the humanoid robot quasi-statically exerts a force.

There is a strong demand for the formulation of the impact dynamics of a humanoid robot to solve the following problems:

- *Working postures*: An optimum working posture at the impact tasks must be analyzed in order to minimize the angular momentum caused by an impulsive force. The angular momentum is more crucial than the translational momentum, because a humanoid robot easily falls down by a large angular momentum.
- *Impact motion synthesis*: Appropriate impact motions of a humanoid robot must be synthesized based on multibody dynamics, to exert a large force on an environment.
- *Stability analysis*: Exerting a large force on an environment, a humanoid robot must keep the balance. Therefore, stability analysis for the impact tasks is inevitable.
- *Shock absorbing control*: In order to minimize the bad effect caused by the discontinuous velocity, shock absorbing control algorithms must be studied.
- *Enrichment of applications*: Applications of the impact tasks must be developed to clearly show the advantages of using the impulsive force.

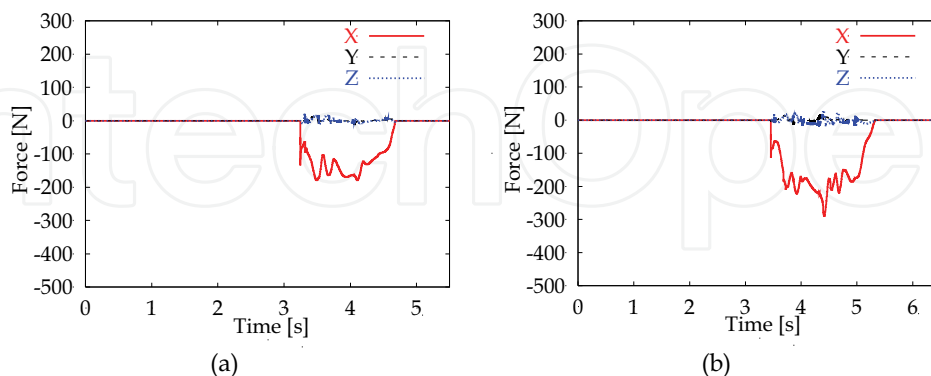


Fig. 3. Force generated at the wrist. (a) When the humanoid robot exerts a quasi-static force on a wall. (b) When the humanoid robot exerts an impulsive force on a wall.

3. A Humanoid Robot HRP-2 and Control System Software

3.1 Specifications of the HRP-2

A humanoid robot HRP-2 was developed in the Humanoid Robotics Project (1998–2002) being supported by the Ministry of Economy, Trade and Industry (METI) through New Energy and Industrial Technology Development Organization (NEDO). The total robotic system was designed and integrated by Kawada Industries, Inc. and Humanoid Research Group of the National Institute of Advanced Industrial Science and Technology (AIST).

The height and weight of the HRP-2 are respectively 154 cm and 58 kg including batteries. The HRP-2 has 30 degrees of freedom (DOF). Please see the official web page of the HRP-2 ([http://www.kawada.co.jp/global/ams/hrp\\_2.html](http://www.kawada.co.jp/global/ams/hrp_2.html) ) for more details.

In order to perform the drum beating and Bojutsu, small modifications are applied to the HRP-2. The arrangement of the wrist DOF is modified from the original, i.e. the last DOF at the wrist is pronated 90 °. Furthermore, gloves are developed and attached to the hands to grip firmly the sticks.

3.2 Control system software

The control system software of the HRP-2 is supplied and supported by General Robotics Inc. The control system software provides a controller that can be used with the CORBA servers of OpenHRP (Hirukawa et al., 2003). As shown in Fig. 4, the controller is composed of many plugin softwares. The control system software also includes the I/O access library to access the lower level functions of the robot and a VRML simulator model of the HRP-2 and various utilities.

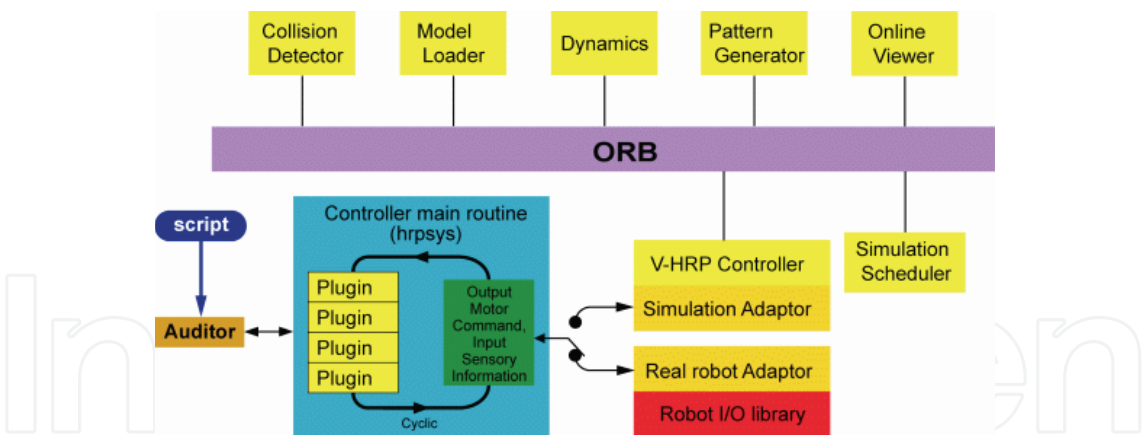


Fig. 4. Control system software of the HRP-2 with OpenHRP (the figure is quoted from [http://www.generalrobotix.com/product/openhrp/products\\_en.htm](http://www.generalrobotix.com/product/openhrp/products_en.htm)).

Foundational plugins such as *Kalman Filter*, *Sequential Playback*, *Walk Stabilizer*, *Pattern Generator*, *Dynamics*, *Logger*, and *ZMPSensor* are also included in the control system software, however, users can develop own functions as a plugin to enrich the humanoid robot motions. Please see the official web page [http://www.generalrobotix.com/product/openhrp/products\\_en.htm](http://www.generalrobotix.com/product/openhrp/products_en.htm) for more details of the control software.

4. Drum Beating

4.1 Primitive poses and motions

In order to generate drum beating motions of the humanoid robot HRP-2, the motion is decomposed into four primitive poses or motions: (a) initial pose, (b) swing, (c) impact, and (d) withdrawing, as shown in Fig. 5. Among the four primitive motions, impact and withdrawing are important to exert an impulsive force. As presented in Fig. 6, three different swing patterns, (a) small swing, (b) middle swing and (c) big swing, are generated sharing the poses for the impact and withdrawing. For these swing patterns, three different initial poses are given and the poses to pass through in swing motion are designed. Cubic spline is used to interpolate the given poses.

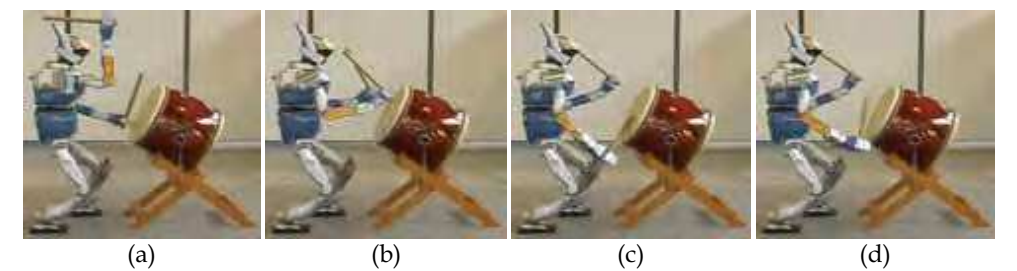


Fig. 5. Four primitive poses or motions in a drum beating. (a) Initial pose. (b) Swing. (c) Impact. (d) Withdrawing.

4.2 Synchronization with music

The swing motion must be synchronized with music in the drum beating. For the synchronization, a beat timing script is prepared for each tune. An example of the script is listed as follows:

```
0.500  RS
1.270  LM
1.270  RM
0.635  LS
...
0.500  END
```

The numbers listed in the first column indicate the interval (s) to the next beating. The symbols listed in the second column indicate the way of beating. The first character 'R' or 'L' indicates the arm to move (Right or Left), while the second character 'S', 'M', 'B', or 'E' indicates the kinds of swing (Small swing, Middle swing, Big swing, or Edge beating, see Fig. 6).

For example, the third line of the script "1.270 RM" indicates "beat the drum after 1.270 s using the middle swing of the right arm." The period between the impact and the previous pose is fixed to 0.1 s to achieve the maximum speed at the impact. As shown in Fig. 6 (b), seven intermediate poses are designed for the middle swing between the initial pose and the impact, therefore, if the duration is specified to 1.270 s, each period  $\Delta T_M$  between the poses is calculated as follows:



$$\Delta T_M = \frac{\text{duration} - 0.1}{\text{number of poses}} = \frac{1.270 - 0.1}{7}.$$

(1)

The duration time varies depending upon a tune.  
There are two restrictions in the script: (i) the first beating must be RS (small swing of right arm), (ii) right arm and left arm must be alternating to beat.

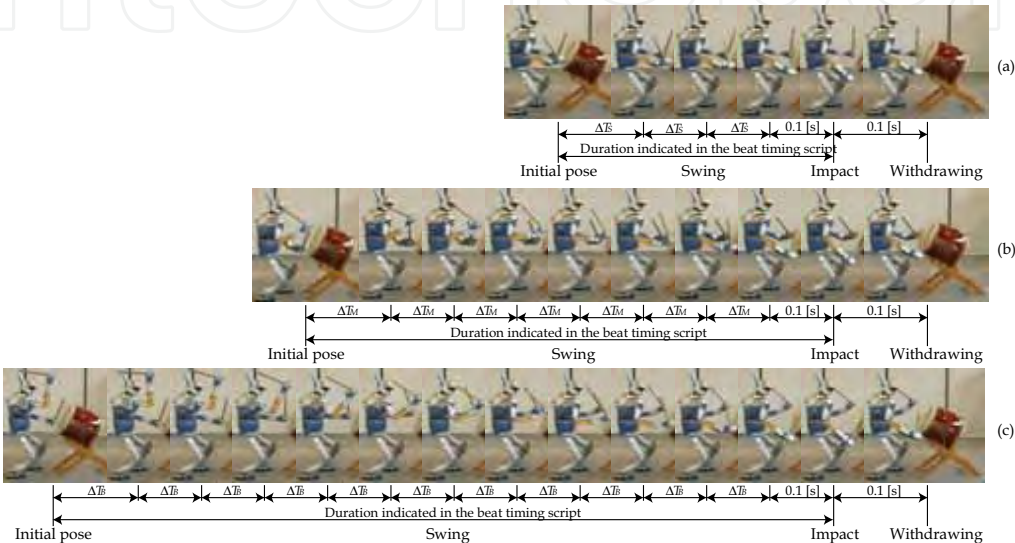


Fig. 6. Three swing patterns. The periods between impact and the previous pose, and between withdrawing and impact are fixed to 0.1 [s]. Other periods denoted by  $\Delta T_s$ ,  $\Delta T_M$ ,  $\Delta T_B$ , are computed from the duration indicated in the beat timing script. (a) Small swing. (b) Middle swing. (c) Big swing.

4.3 Control software

Fig. 7 presents the flow of the control system. The components marked with red boundary boxes are developed in this work.

Firstly, wav files of the three tunes are prepared: (i) *ware wa umi no ko* (I am a son of the sea), (ii) *Tokyo ondo* (Tokyo dance song), and (iii) *mura matsuri* (village festival). They are very old and traditional tunes, and thus, copyright free. As soon as the Speak Server receives a queue from the robot control system, the server starts playing the tune. The queue is used to synchronize the tune with the drum beating motion.

Secondly, the timings of beating are scheduled by hand. In order to strictly count the timing, a time keeping software is newly developed. The time keeping software counts the rhythm of a tune. The timings of the beating are described in a script file as mentioned in Section 2.

Thirdly, a plugin software is developed as a shared object to generate drum beating motions interpreting the beat timing script.

Fourthly, interpolating the given poses presented in Fig. 6 using cubic spline, trajectories of all joints are produced online. The produced trajectories are given to the humanoid robot through a plugin *SeqPlay*.

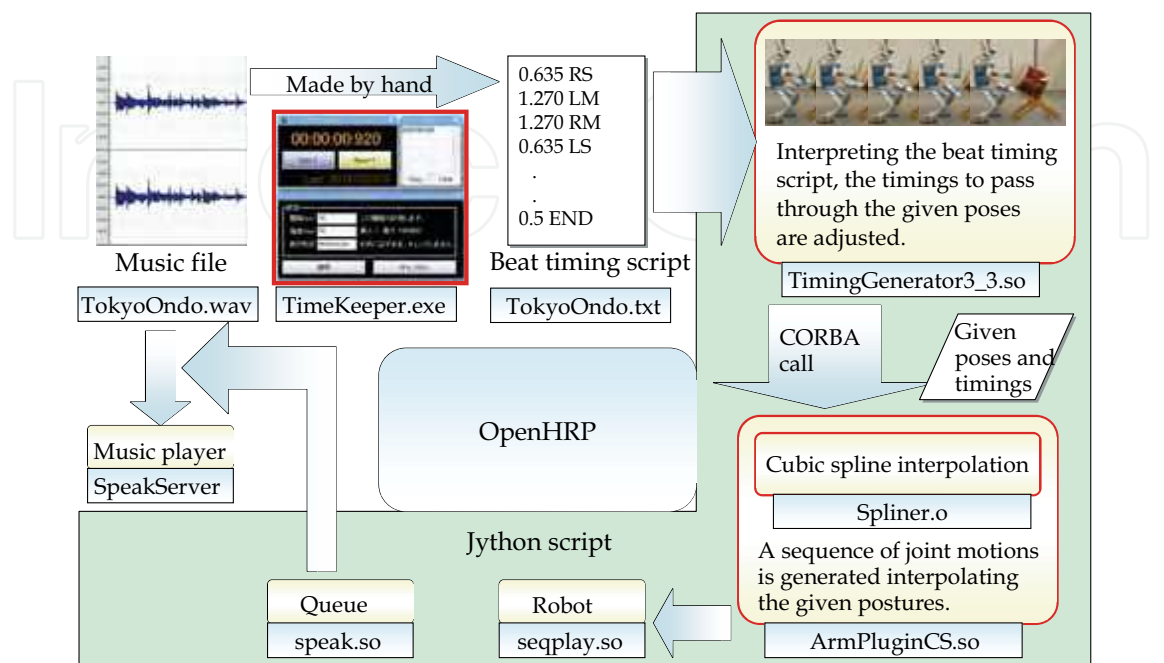


Fig. 7. A software diagram. The components marked with red boundary boxes are developed in this work.

4.3 Resultant joint trajectories

The reference and resultant joint trajectories of the elbow and wrist joints of the right arm are plotted in Fig. 8. The error in the impact time was approximately 30 [ms], which was not significant in the synchronization with music.

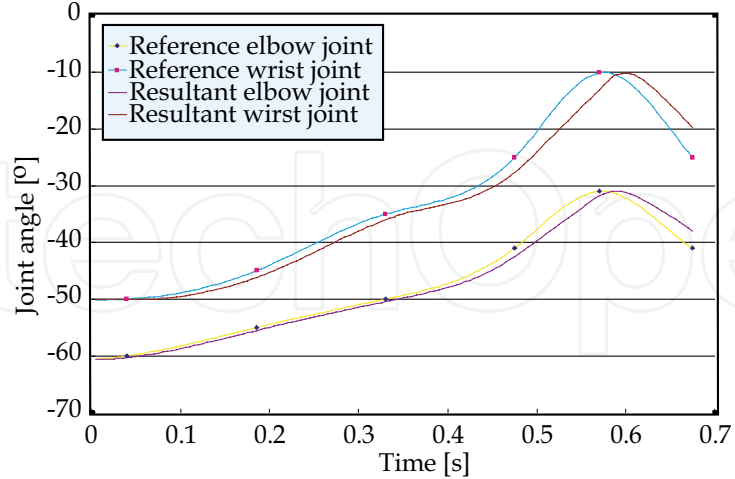


Fig. 8. A software diagram. The components marked with red boundary boxes are developed in this work.



As can be seen in Fig. 7, during the last 0.1 [s] before the impact (approximately from 0.5 to 0.6 [s]), gradients of the joint trajectories are steep compared with other periods. Since the period between the impact and the previous pose is set to 0.1 [s], maximum joint speed is almost achieved.

5. A Japanese Martial Art Bojutsu

In martial arts, impulsive forces are frequently used to fight with an antagonist. A Japanese martial art Bojutsu was also demonstrated by the humanoid robot HRP-2 in Aichi Exposition, although an impact was not performed in the demonstration. Some dynamic motions used in the demonstration are presented in Fig. 9.

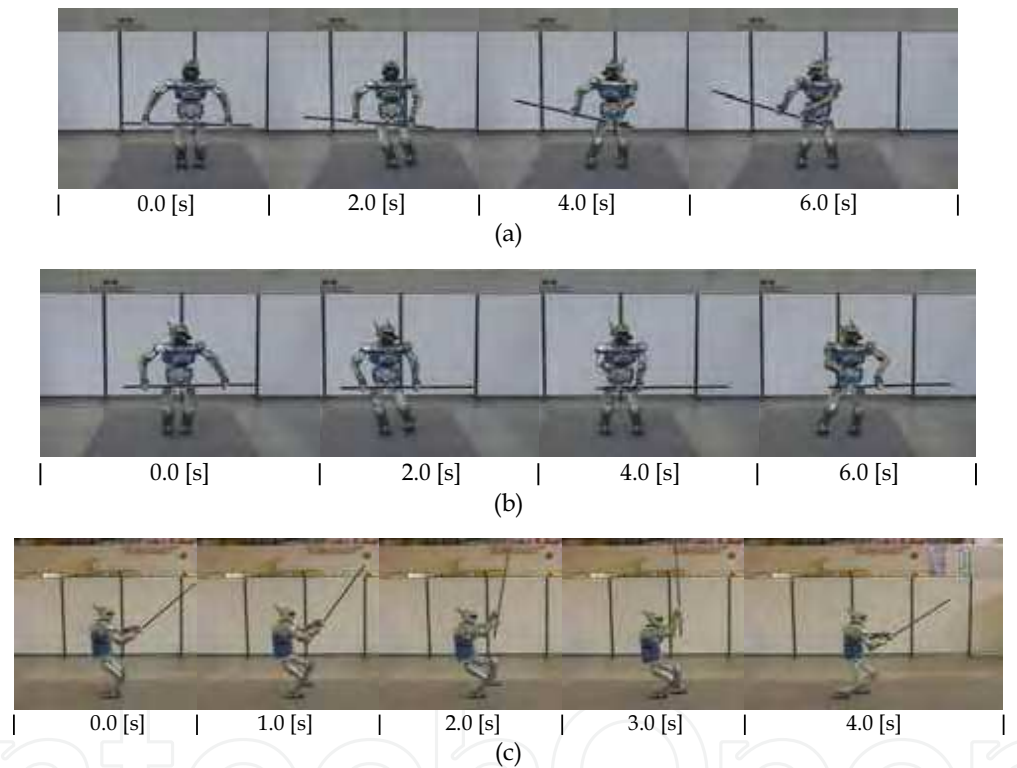


Fig. 9. The Japanese martial art Bojutsu motion patterns. (a) Thrusting a staff weapon rightward. (b) Thrusting a staff weapon leftward. (c) Banging down a staff weapon.

6. Demonstration at Aichi Exposition

The Prototype Robot Exhibition was held for 11 days from June 9 to 19, at the Morizo and Kiccoro Exhibition Center, a convention venue in the Aichi Expo site. The Prototype Robot Exhibition was organized by the Japan Association for the 2005 World Exposition and the New Energy and Industrial Technology Development Organization (NEDO). 63 prototypes performed demonstrations during the period.

The drum beating and Bojutsu demonstration was performed twice a day in the Prototype Robot Exhibition (Fig. 10).



Fig. 10. Demonstrations at Aichi Exposition 2005. (a) Drum beating performance. (b) A Japanese martial art Bojutsu performance.

## 7. Conclusion

This chapter proposed to utilize an impulsive force for humanoid robots to exerts a large force beyond the torque limitations of actuators. The problems of the impact tasks to be solved in the future work were brought up in Section 2.

A drum beating is taken as a case study, because it is a typical task that requires large impulsive forces. The details of the drum beating and a Japanese martial art Bojutsu performed by a humanoid robot HRP-2 in the Aichi Exposition were presented in this paper.

## 8. Acknowledgement

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For many years, the human being has been trying, in all ways, to recreate the complex mechanisms that form the human body. Such task is extremely complicated and the results are not totally satisfactory. However, with increasing technological advances based on theoretical and experimental researches, man gets, in a way, to copy or to imitate some systems of the human body. These researches not only intended to create humanoid robots, great part of them constituting autonomous systems, but also, in some way, to offer a higher knowledge of the systems that form the human body, objectifying possible applications in the technology of rehabilitation of human beings, gathering in a whole studies related not only to Robotics, but also to Biomechanics, Biomimetics, Cybernetics, among other areas. This book presents a series of researches inspired by this ideal, carried through by various researchers worldwide, looking for to analyze and to discuss diverse subjects related to humanoid robots. The presented contributions explore aspects about robotic hands, learning, language, vision and locomotion.

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